The Energy Frontier

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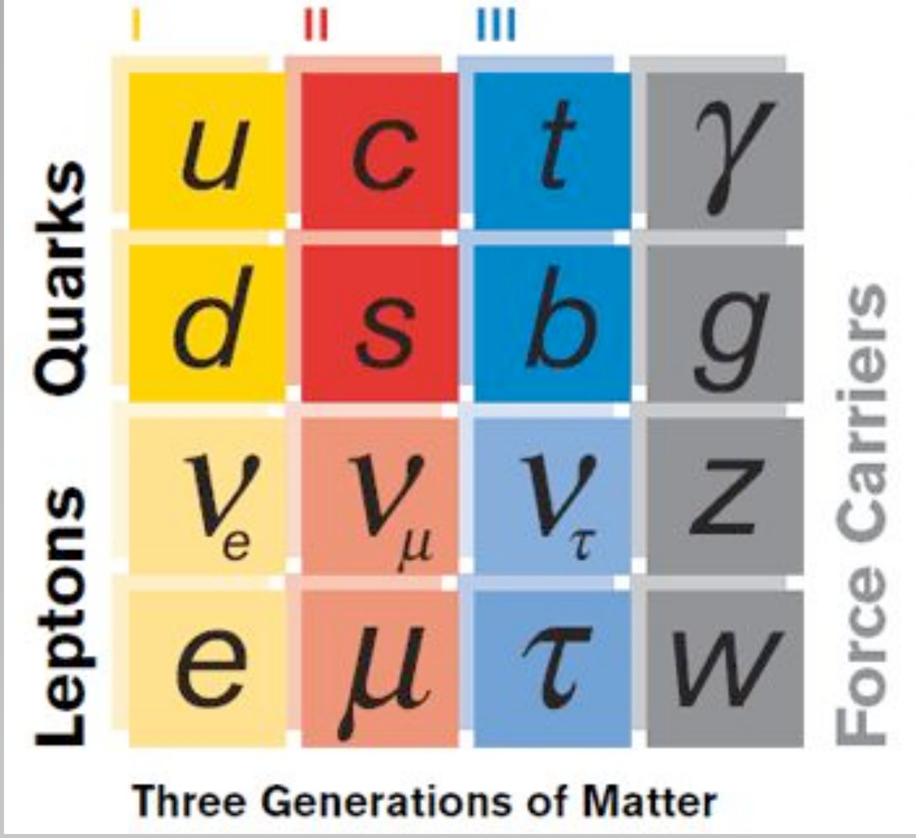
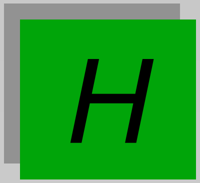
DOE Review, LBNL, March 2007

The Standard Model

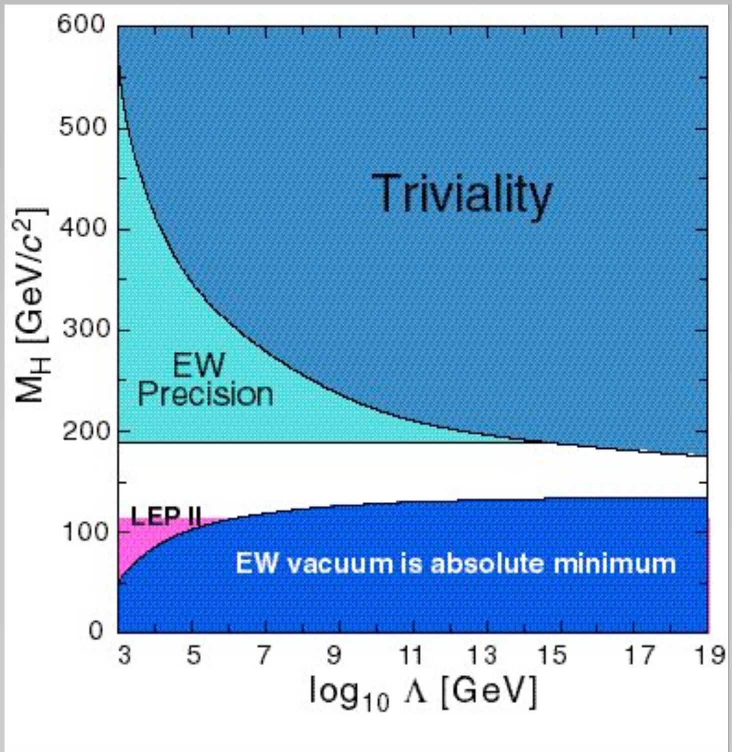
- Matter is made out of fermions:
  - quarks and leptons
  - 3 generations
- Forces are carried by Bosons:
  - Electroweak: γ,W,Z
  - Strong: gluons
- Higgs boson:
  - Manifestation of scalar field that breaks the electroweak symmetry
    - Gives mass to particles
  - Not observed yet
    - Observation critical for understanding electroweak symmetry breaking

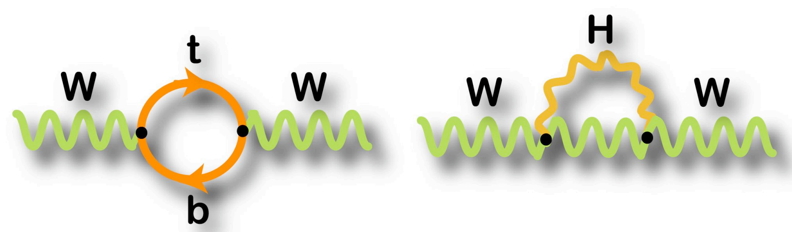


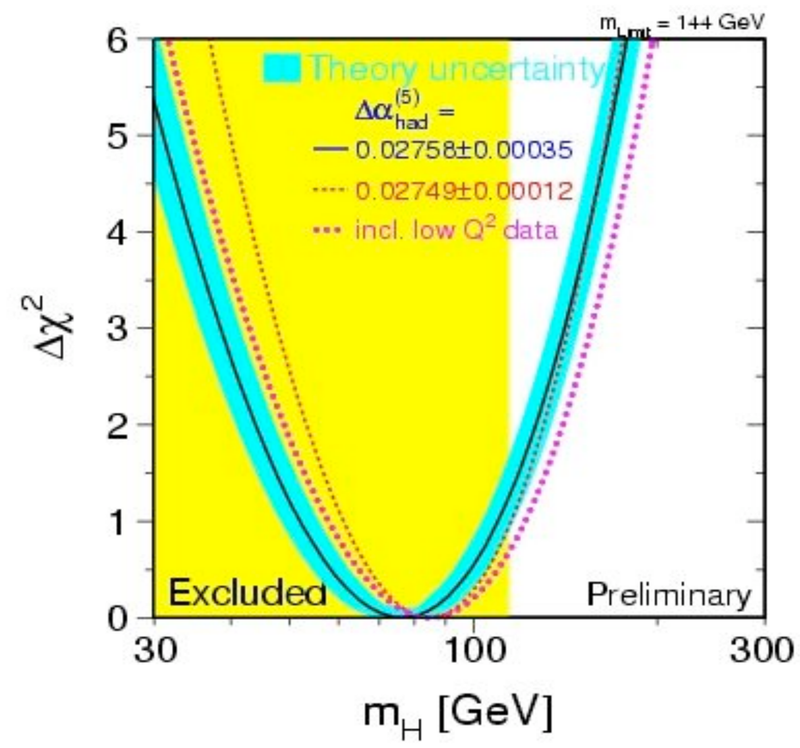


The Higgs boson: what do we know?

- Precision measurements of
  - M_W =80.398 ± 0.025 GeV/c²
  - M_{top}=170.9 ± 1.8 GeV/c²
- Prediction of higgs boson mass within SM due to loop corrections
  - Most likely value: 76^{+33}_{-26} GeV
- Direct limit (LEP): m_h>114.4 GeV

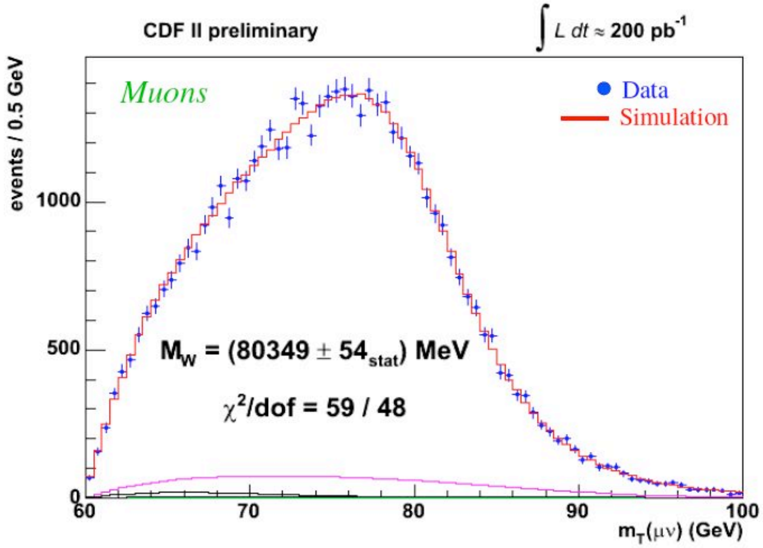


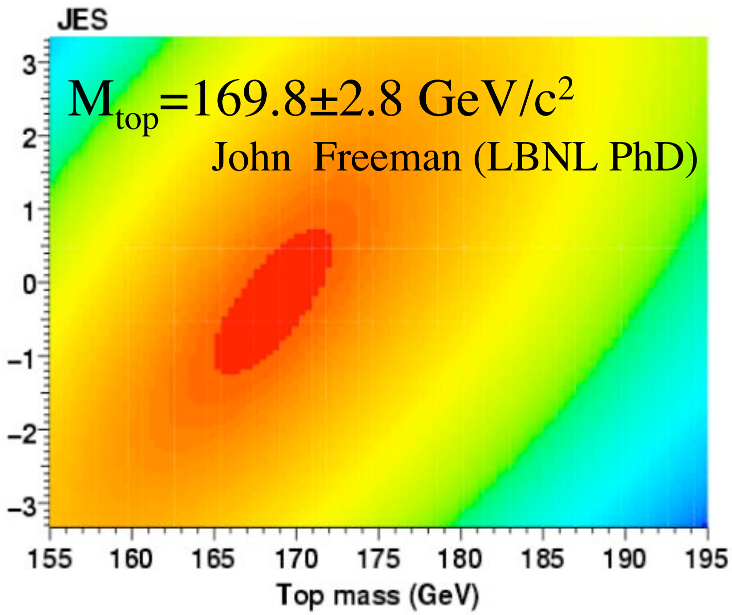




- m_H<144 GeV @95%CL
  - < 182 GeV with LEP2 limit
  - < 97 GeV without $A_{FB}^{b/c}$ (Chanowitz)

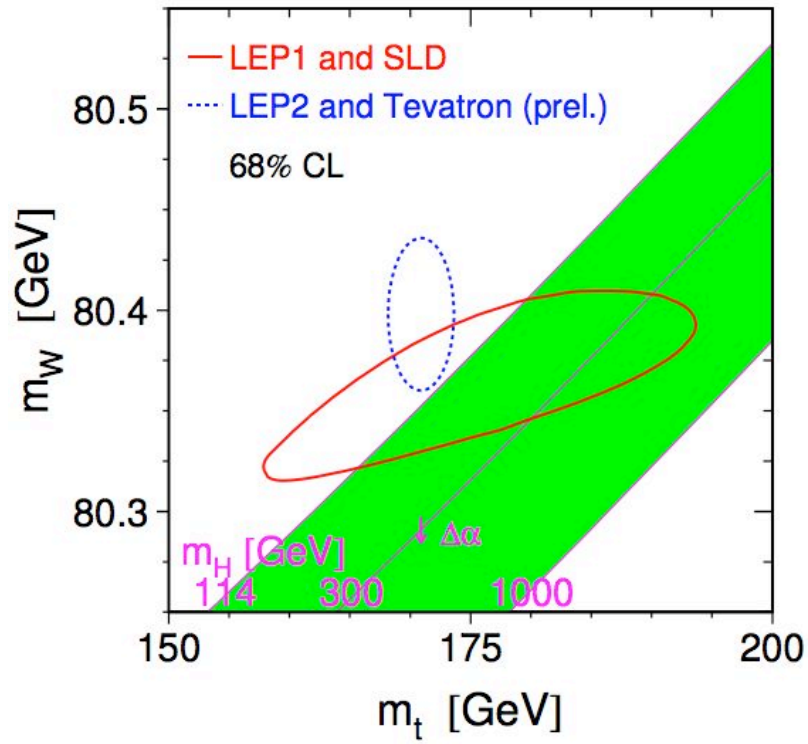
Recent W and Top Mass Results





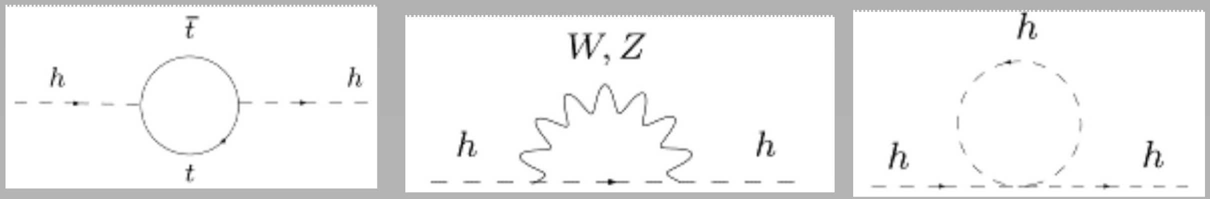
M_{top}=169.8±2.8 GeV/c^2

John Freeman (LBNL PhD)



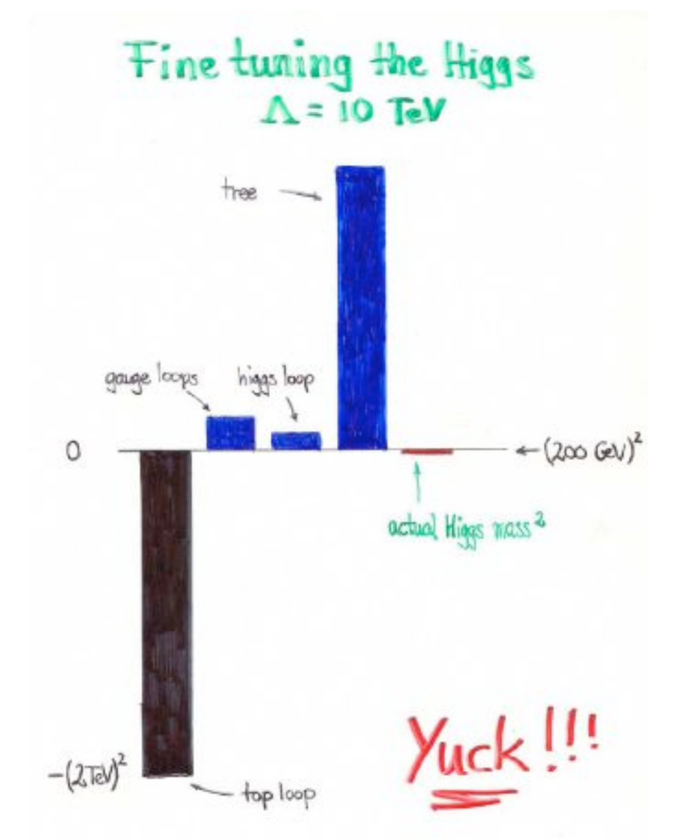
- SM excluded at 68% CL
  - Perfectly allowed at 95% though

Problems of the Standard Model



$$m^2_H \approx (200\text{ GeV})^2 = m^2_H{}^{tree} + \delta\, m^2_H{}^{top} + \delta\, m^2_H{}^{gauge} + \delta\, m^2_H{}^{higgs}$$

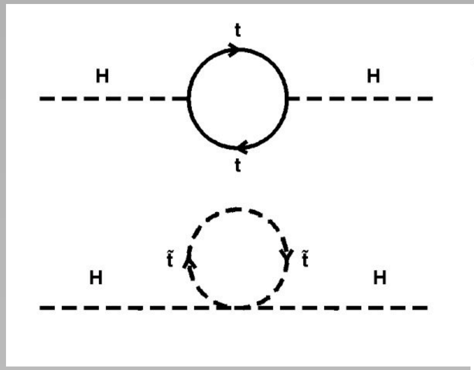
- Large fine-tuning required:
  - $m_H \ll m_{Pl}$
- Accounts for just 4% of the Universe
  - No dark matter candidate
  - Cosmological constant problem
- No prediction for
  - fundamental constants, unification of forces, number of generations, mass values and hierarchy of SM particles, anything to do with gravity

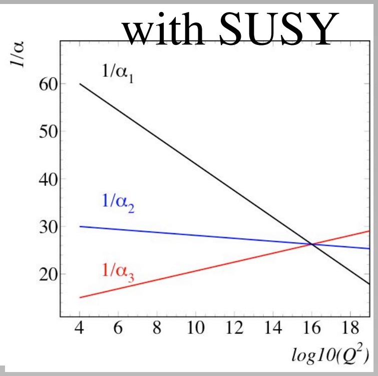


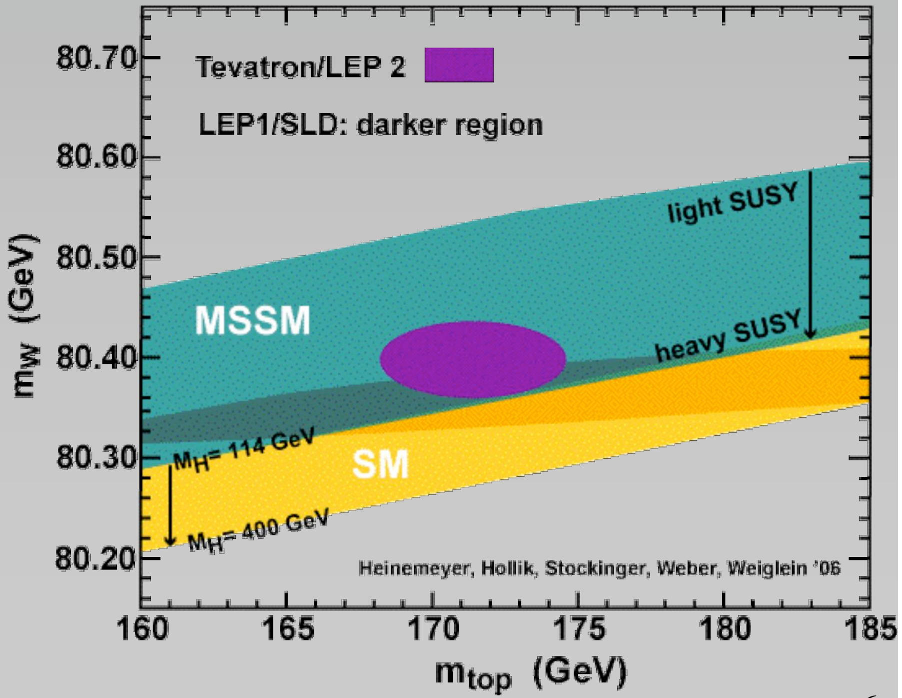
M. Schmaltz, ICHEP 02

What's Nice about SUSY?

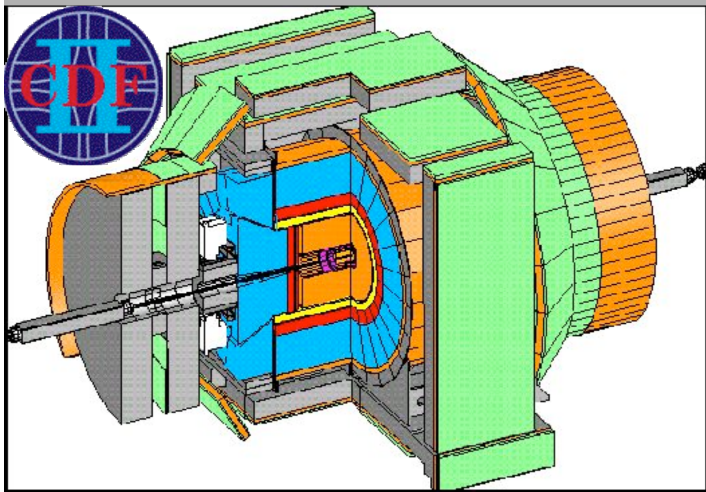
- Radiative corrections to Higgs acquire SUSY corrections:
  - No/little fine-tuning required
  - Particles masses must be near EWK scale
- Unification of forces possible
- Dark matter candidate exists:
  - lightest neutral gaugino
- Changes relationship between m_W, m_{top} and m_H:
  - Also consistent with precision measurements of M_W and m_{top}

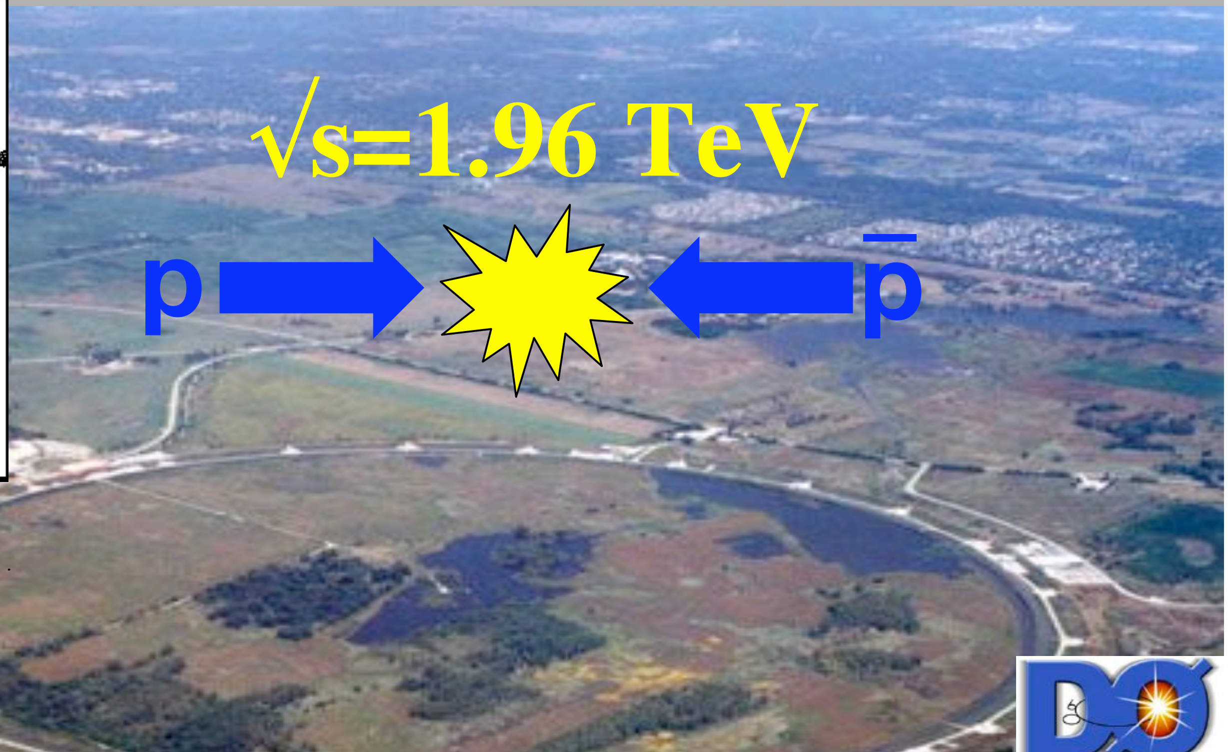


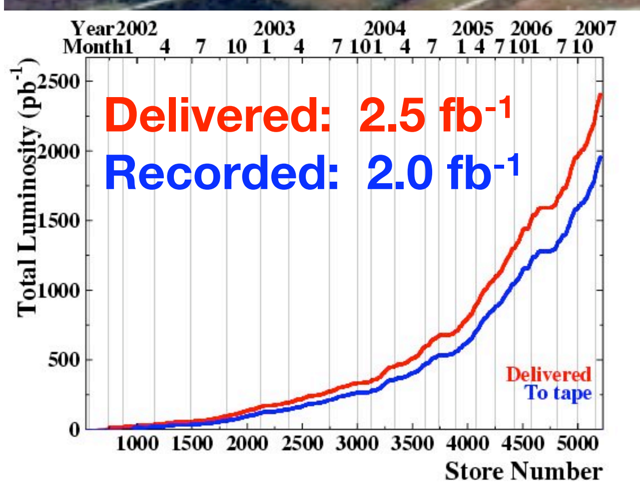


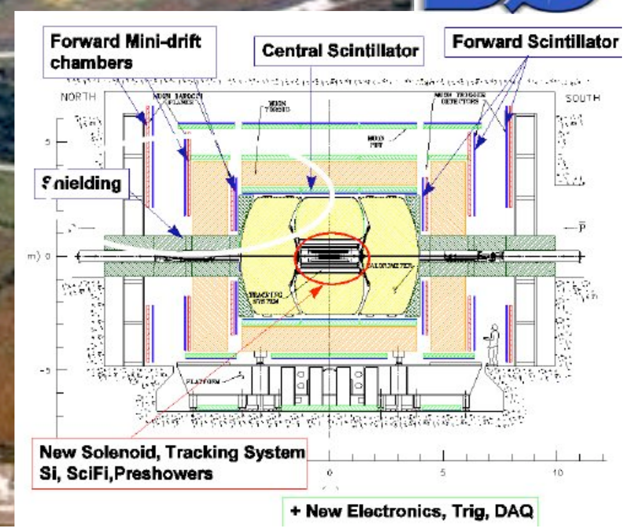


Tevatron Run II

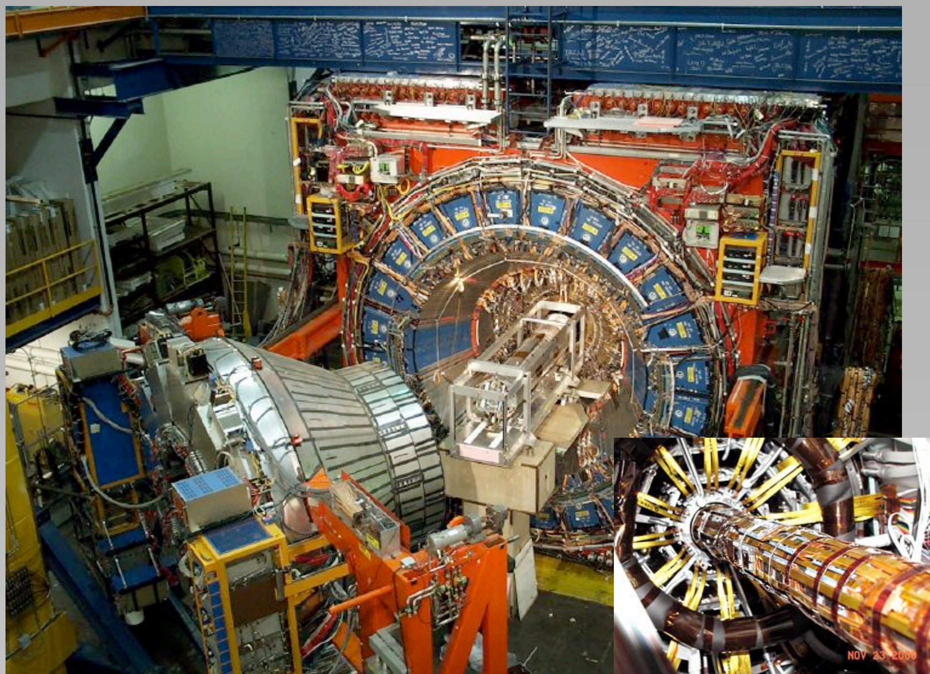








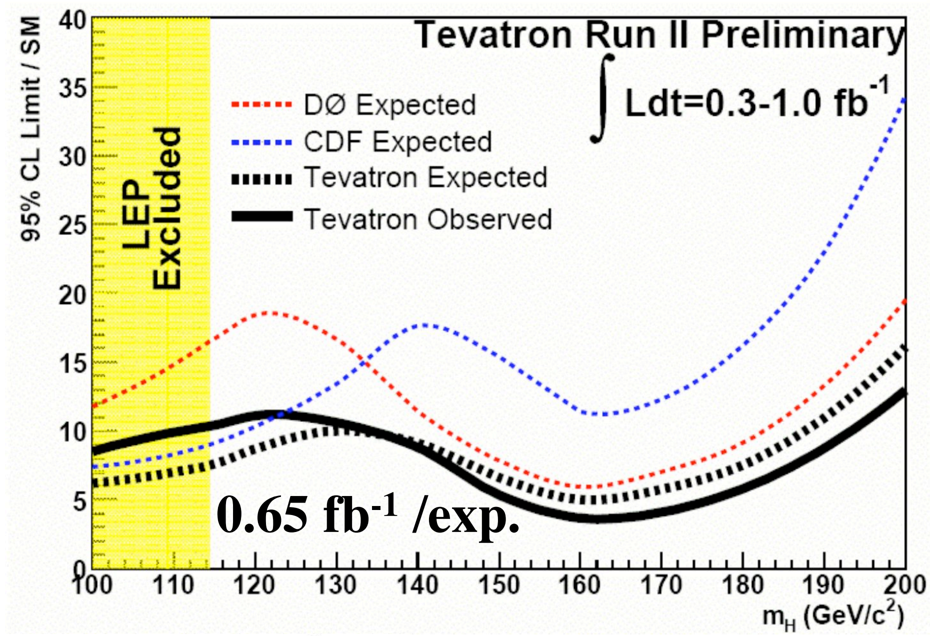
CDF and DØ Detectors

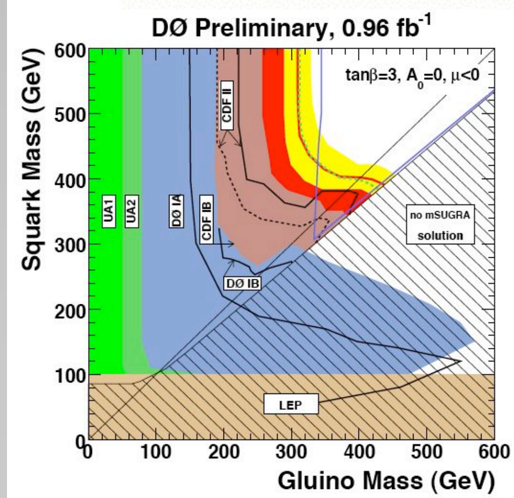


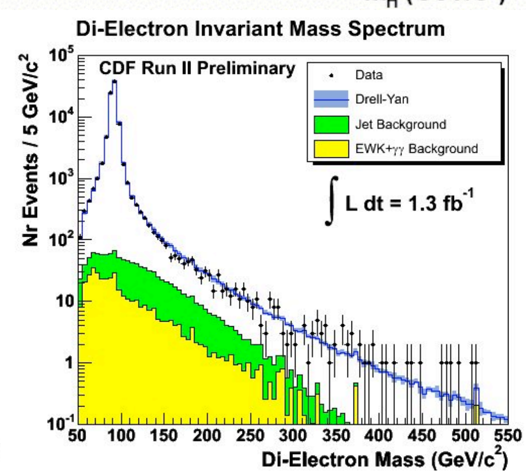
- LBNL has made major contributions to these detectors
  - central to building and operating the CDF silicon detectors for more than 15 years
    - First ever silicon detector at hadron collider
  - crucial contributions to DØ calorimeter and first vertex chamber
- LBNL played a major role in physics exploitation

Status of the Energy Frontier

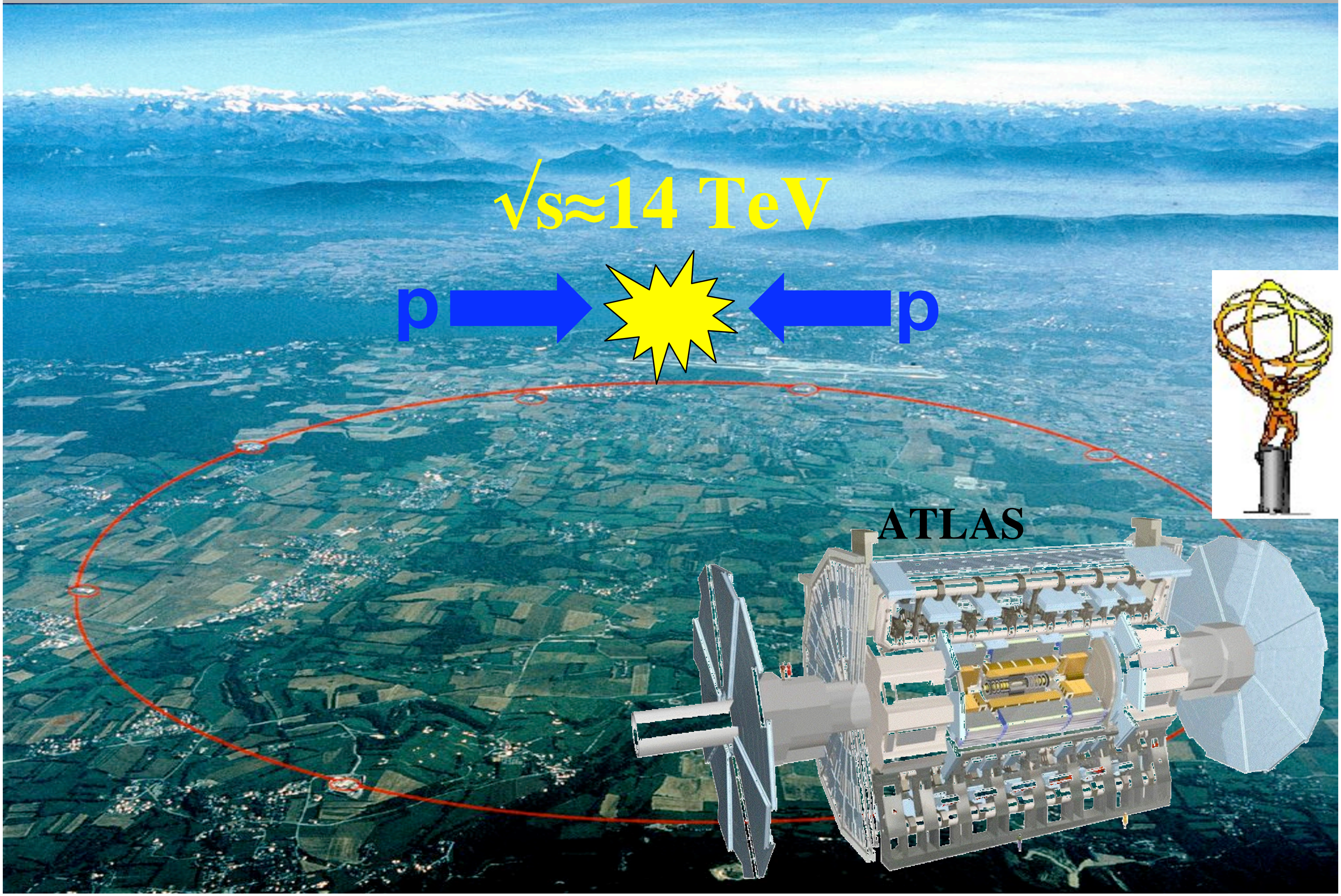
- Higgs boson:
  - LEP: $m_H>114$ GeV
  - Tevatron closing in
- SUSY particles:
  - $m(\tilde{l},\tilde{\chi}^{\pm}_1)>104$ GeV
  - M(LSP)>50 GeV
  - $M(\tilde{g})>310$ GeV
  - $M(\tilde{q})>400$ GeV
- Z′:
  - M>900 GeV (SM Z′)
- Extra dimensions:
  - $M_D>900$ GeV



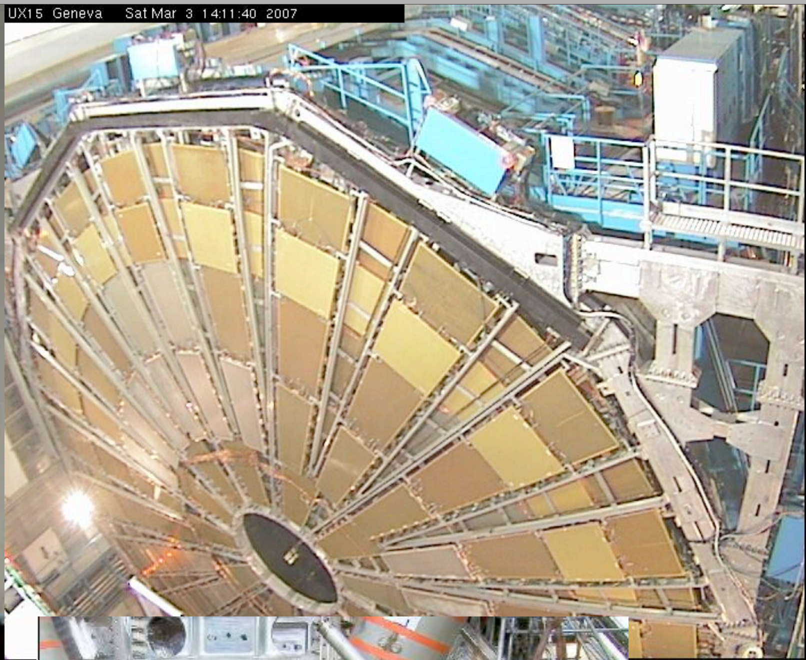


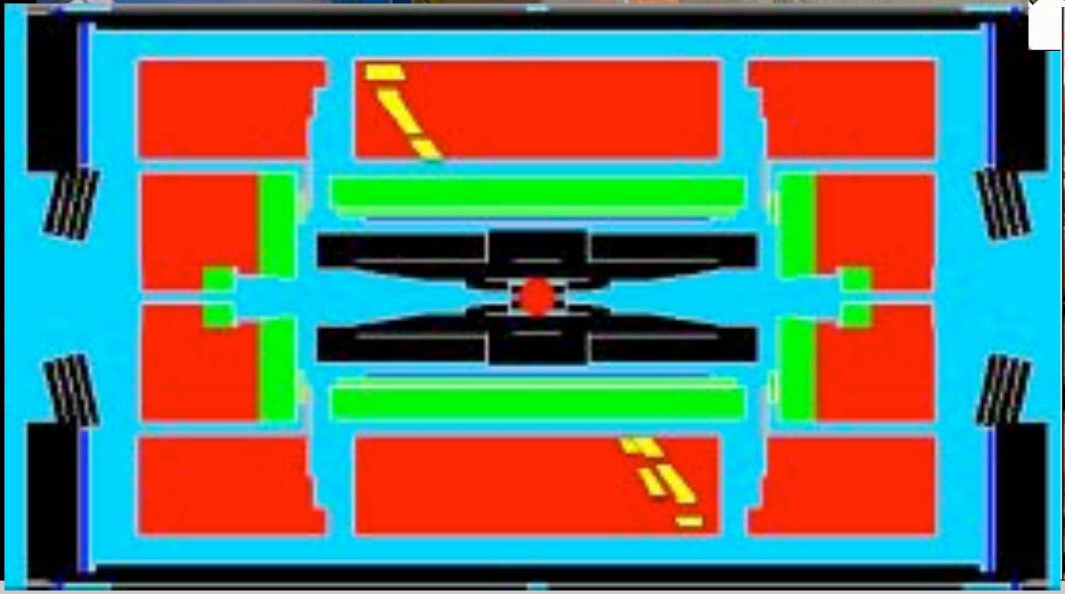


The Large Hadron Collider (LHC)

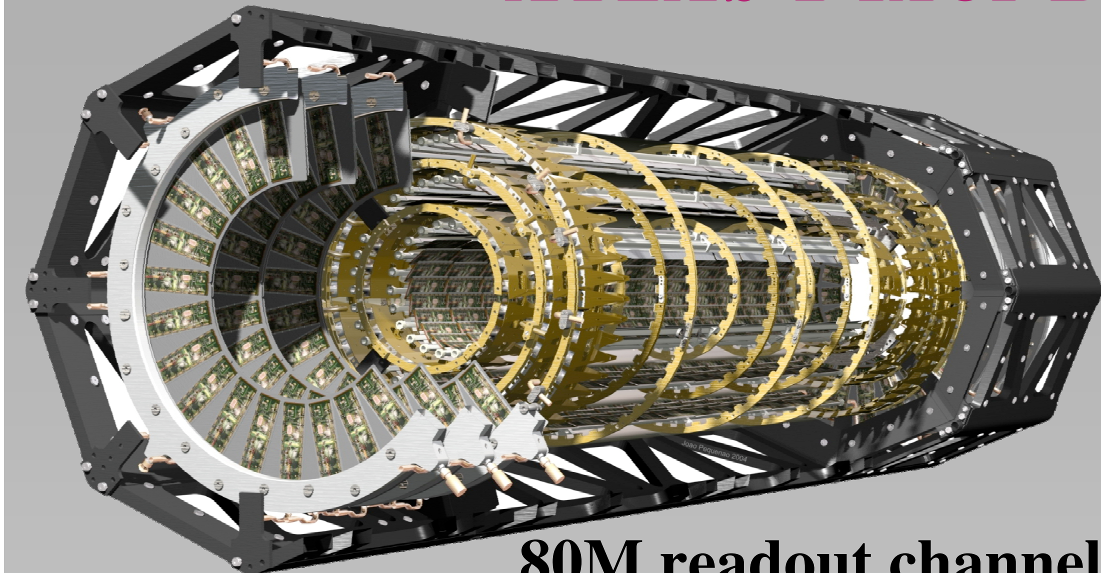


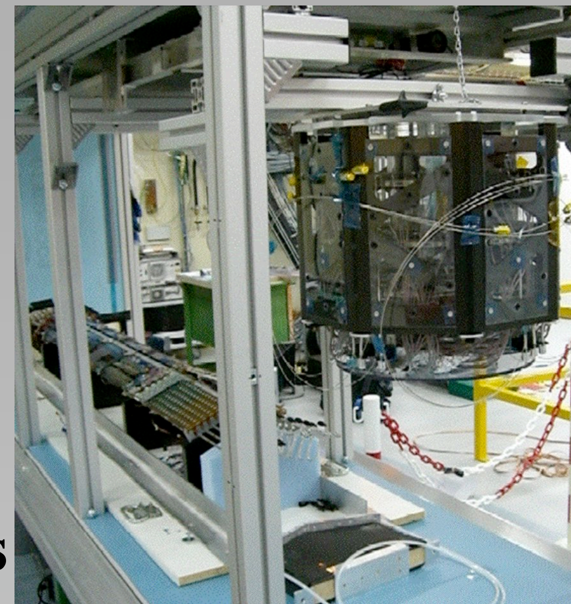
LHC and ATLAS status



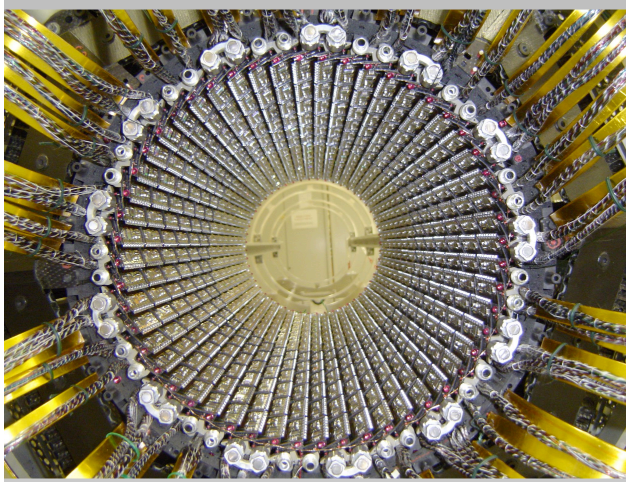


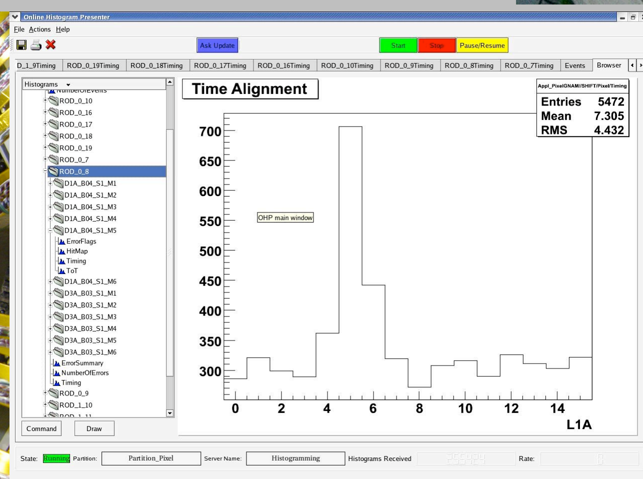
ATLAS Pixel Detector

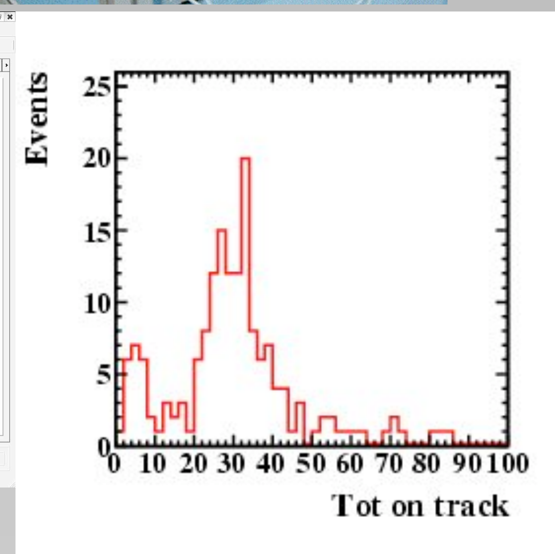




80M readout channels







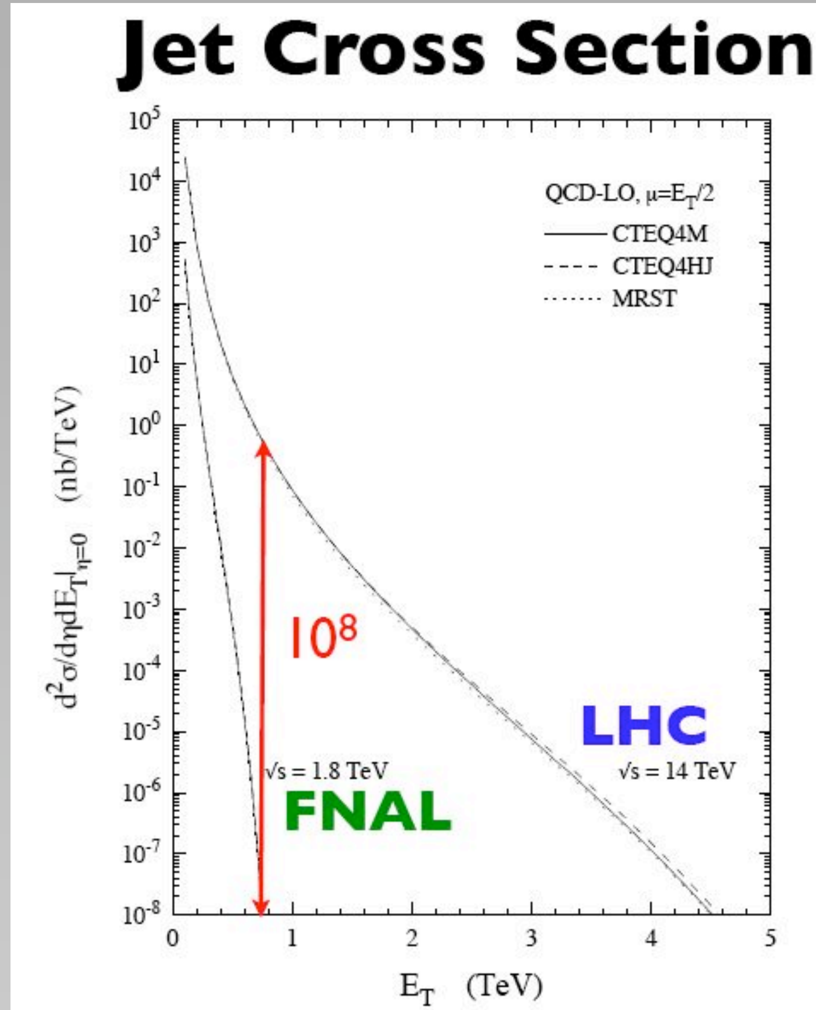
Huge LBNL contributions to both Pixel and SCT detectors

LHC and ATLAS Schedule

- LHC:
  - End of ‘07: a few collisions at $\sqrt{s}$=900 GeV
  - Summer ‘08: first collisions at 14 TeV
- ATLAS:
  - Pixel installation planned for early June ‘07
    - Final schedule may still change
  - Close detector in August ‘07
  - Take cosmics when there is no beam
  - Take data during 900 GeV run
  - On schedule to be ready for 14 TeV run

Physics Opportunities at LHC

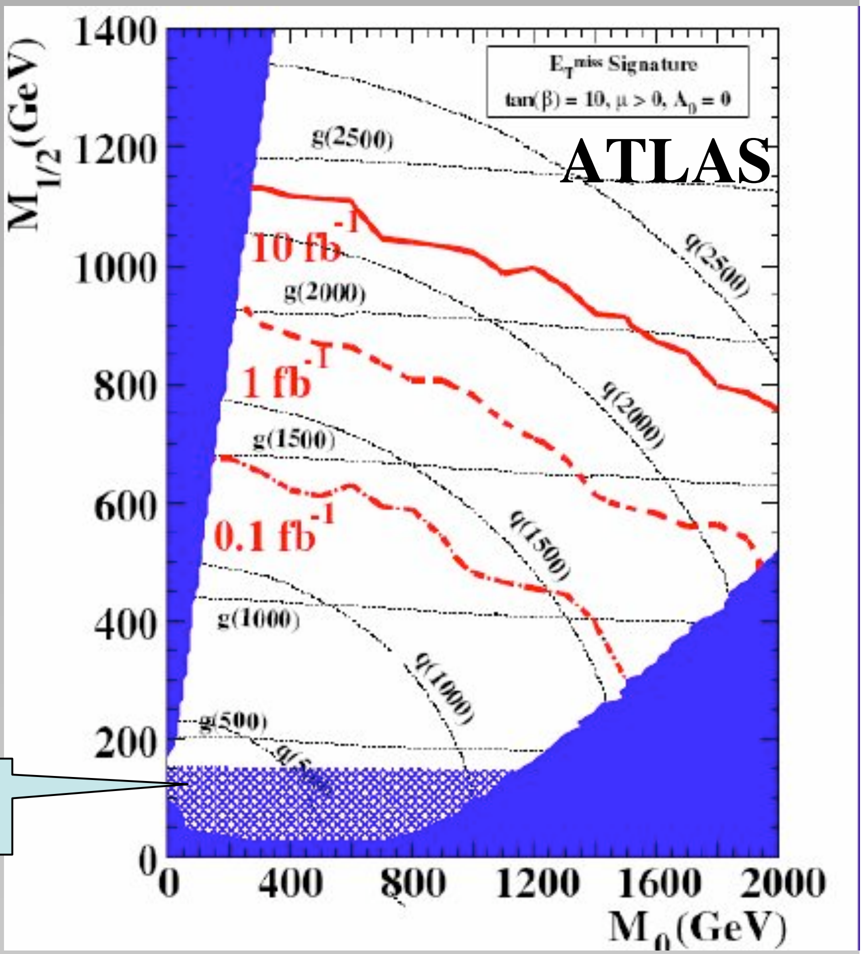
Cross Sections of Physics Processes (pb)			
	Tevatron	LHC	Ratio
$W^{\pm}$ (80 GeV)	2600	20000	10
$t\bar{t}$ (2x172 GeV)	7	800	100
gg->H (120 GeV)	1	40	40
$\tilde{\chi}^{+}{}_{1}\tilde{\chi}^{2}{}_{0}$ (2x150 GeV)	0.1	1	10
$\tilde{q}\tilde{q}$ (2x400 GeV)	0.05	60	1000
$\tilde{g}\tilde{g}$ (2x400 GeV)	0.005	100	20000
Z′ (1 TeV)	0.1	30	300



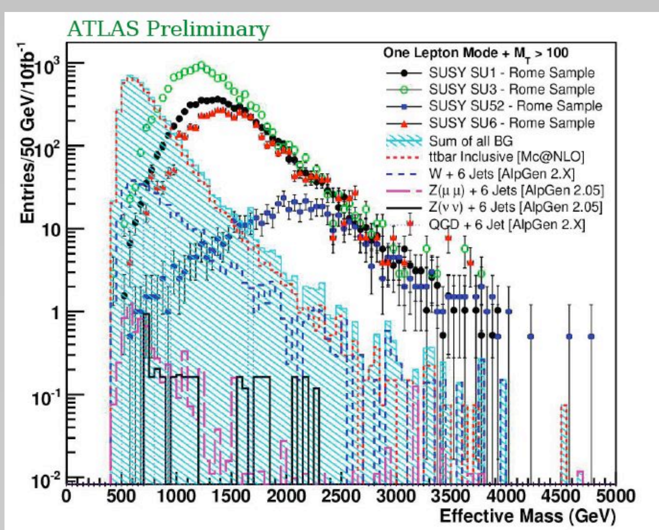
- Amazing increase for strongly interacting heavy particles
  - Opportunity!

SUSY Discovery at the LHC

- May be found relatively quickly!
- Jets+missing E_T analysis most promising:
  - Will improve upon Tevatron sensitivity with only 100 pb^{-1} of data!
- Then the fun really starts:
  - SUSY spectroscopy
  - Sleptons and gauginos are accessible in cascade decays



Tevatron



This signal is rather robust but we need to keep eyes open for other signals

Z´ Discovery Reach

- $Z' \to e^+e^-$ with $m_{Z'}$=1 TeV/c^2 and SM couplings:
  - Tevatron (evaluated for P5 review):
    - 5σ discovery with $\int Ldt$=1.5 fb^{-1}
  - LHC (F. Gianotti, M. Mangano, hep-ph/0504221) :
    - 5σ discovery with $\int Ldt$=70 pb^{-1}

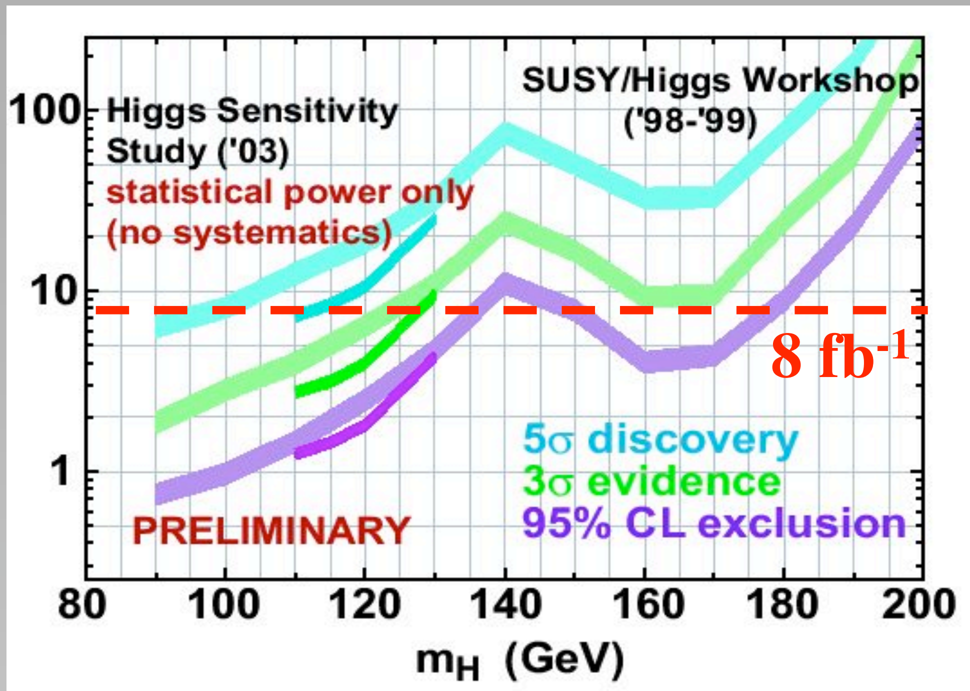
LHC projections (from F. Gianotti, M. Mangano)

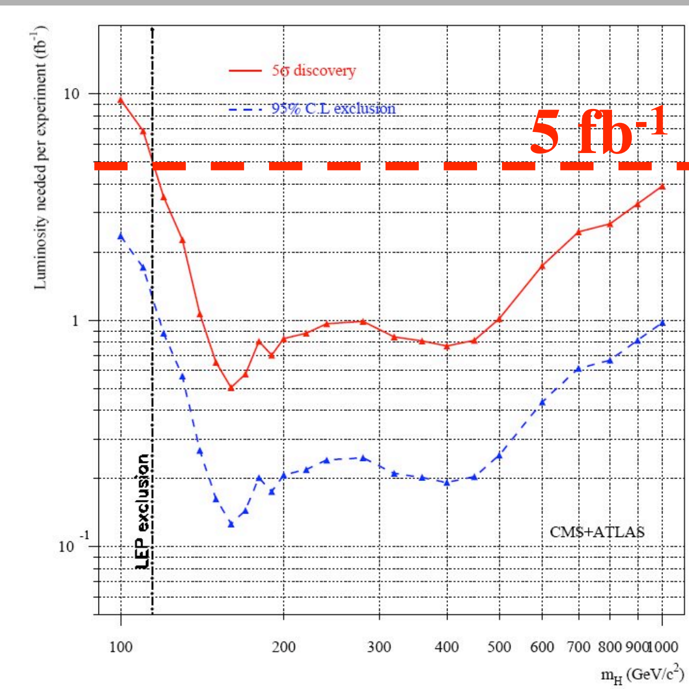
$Z' \to ee$, SSM

Mass	Expected events for 10 fb^{-1} (after all cuts)	$\int L\,dt$ needed for discovery (corresponds to 10 observed evts)
1 TeV	~ 1600	~ 70 pb^{-1}
1.5 TeV	~ 300	~ 300 pb^{-1}
2 TeV	~ 70	~ 1.5 fb^{-1}

"Easy" very early LHC physics (also for more realistic Z′ scenarios)

Higgs Boson Discovery Prospects

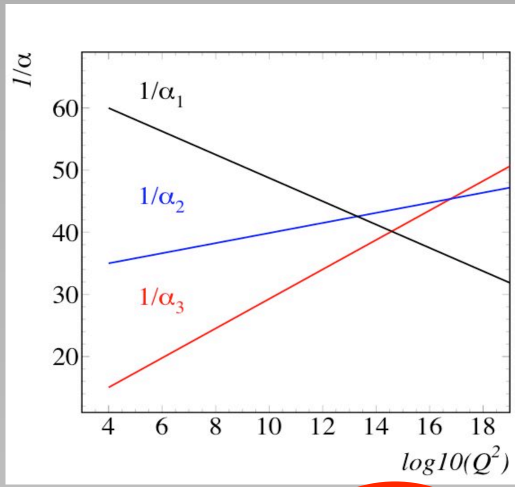


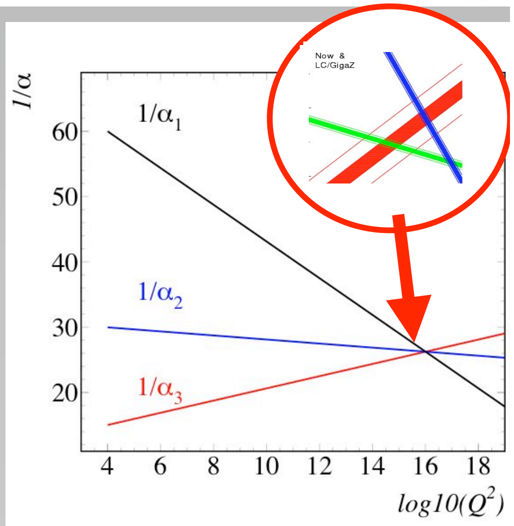


- Tevatron:
  - might see a 3σ evidence with full luminosity (2009/2010?)
- LHC:
  - cover full mass range with 5σ significance with 5 fb^{-1} (2009/2010?)
    - Could be earlier if $m_H \geq 2 * m_W$
  - At low mass sensitive to three production and decay modes:
    - $gg \to H \to \gamma\gamma, WW \to H \to \tau\tau, ttH \to ttbb$

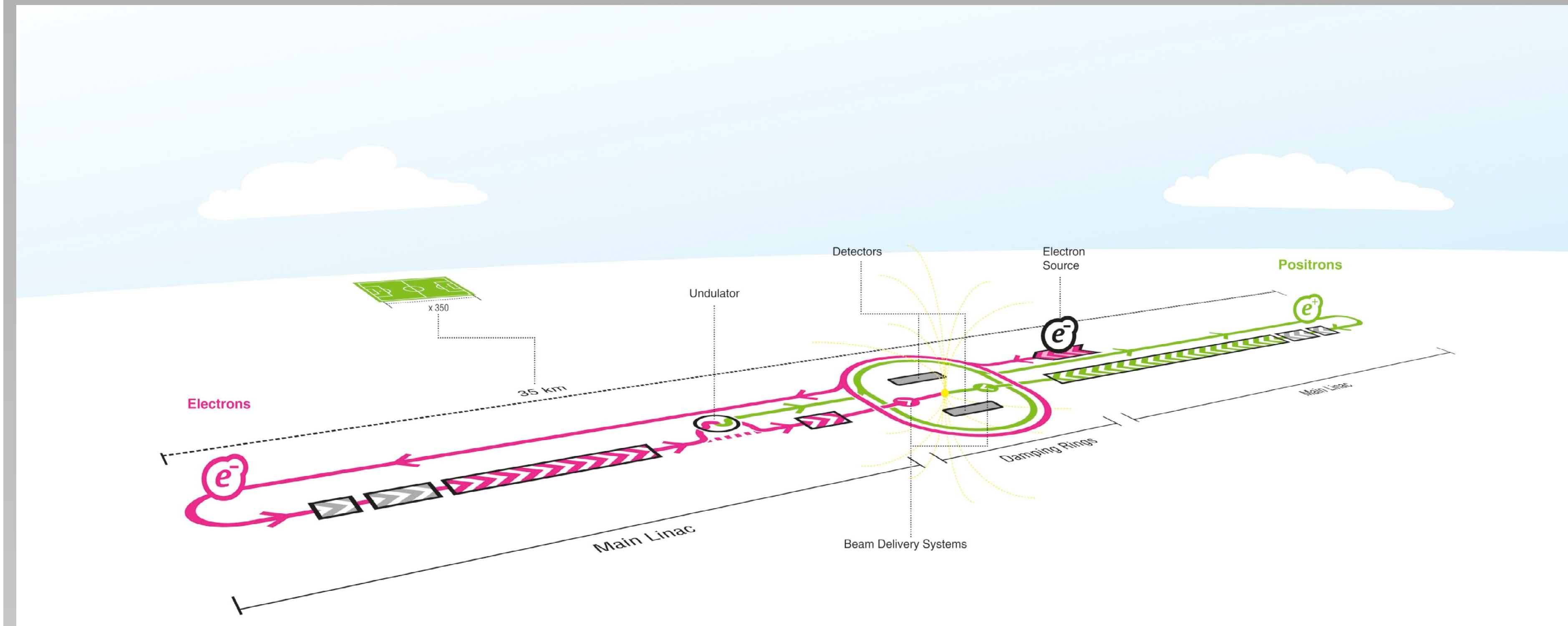
Suppose we find Higgs and SUSY at LHC…

- **LHC sparticle mass reconstruction limited ~ few GeV uncertainty**
  - underconstrained kinematics
- **Is it really SUSY ? and Higgs?**
  - Spin-reconstruction difficult or impossible at LHC
- **Is new model valid to Planck or at least GUT scale ?**
  - need high precision for large extrapolations to GUT scale
- **Does the SUSY LSP account for all Cold Dark Matter ?**
  - Need to know many annihilation cross sections to calculate relic density



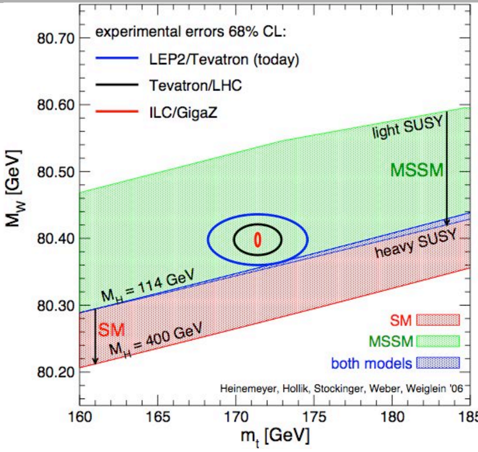


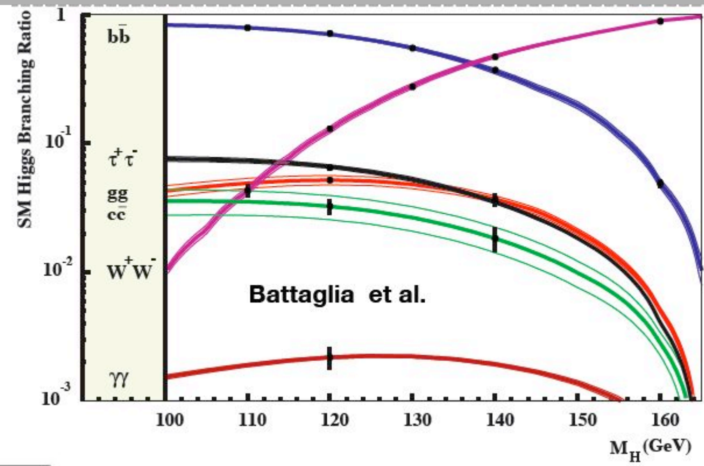
International Linear Collider

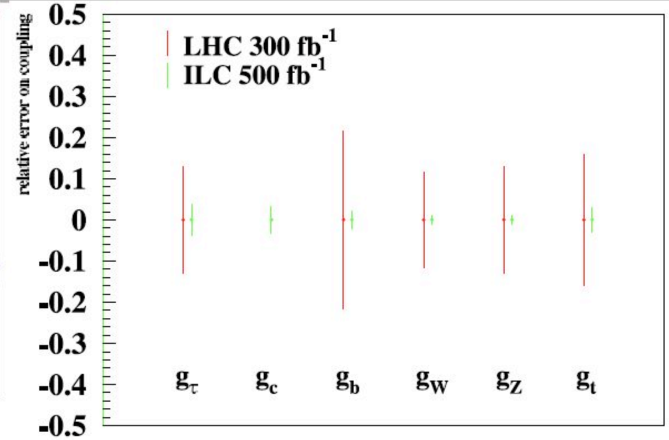


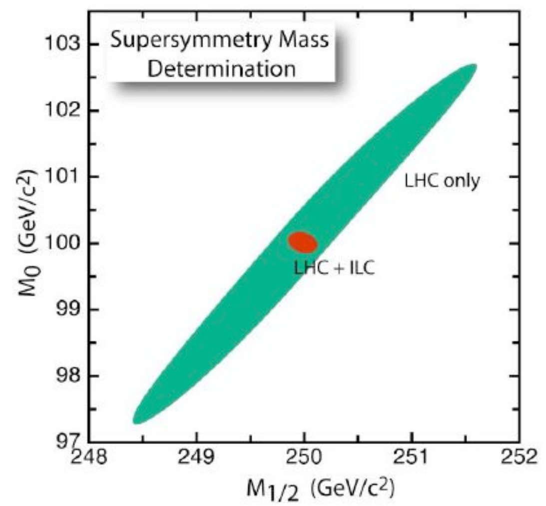
- ILC: 40km long e+e- collider with $\sqrt{s}$=0.5-1 TeV
  - Advantage compared to LHC: initial state precisely known
- See talks by M. Venturini, M. Battaglia

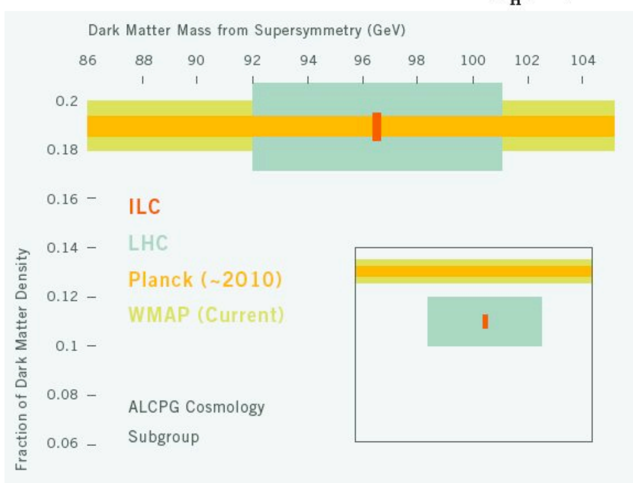
ILC Physics goes beyond LHC

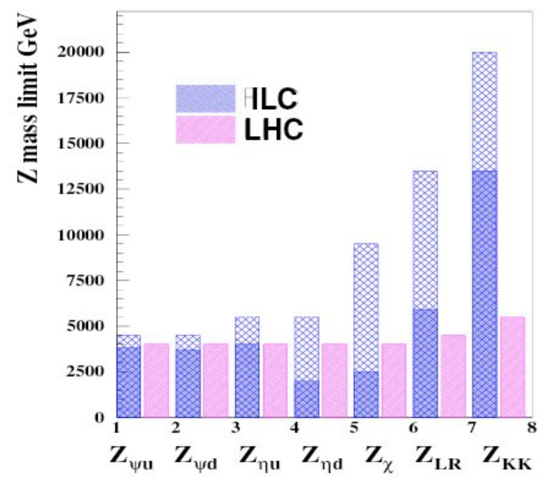








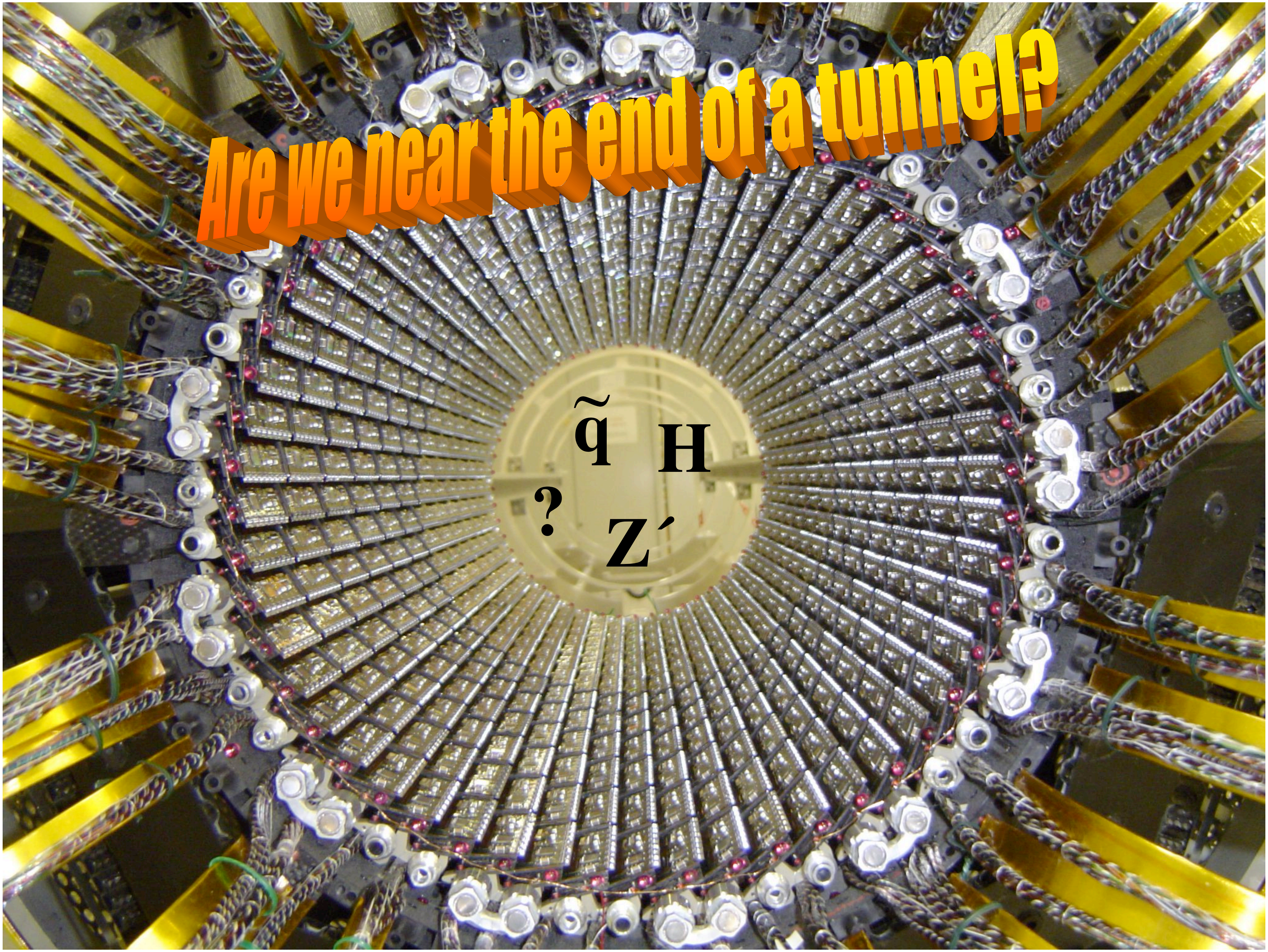




- ILC required to really understand the big questions
  - High precision measurements require excellent precision detectors
  - LBNL focus on silicon pixel sensors for vertexing and TPC for 3D tracking

Conclusions

- **The origin and nature of electroweak symmetry breaking are not understood**
  - Its understanding is likely to involve the existence of new particles at the TeV scale
- **LHC will probe the TeV scale and take over the energy frontier from the Tevatron next year**
  - ATLAS detector is on schedule
  - The physics opportunities are amazing
    - particularly for very massive particles
  - LBNL group is focused on building ATLAS and setting up software to get ready for exploitation of LHC data
    - builds on major contributions to ATLAS (detector and software) and extensive hadron-collider expertise
- **ILC is needed if new physics exists at TeV scale**
  - Provides a chance of understanding physics at GUT scale


Are we near the end of a tunnel?
$\tilde{q}$
H
?
Z´

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